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K. Ouassaa, D. Forsyth, and D. White

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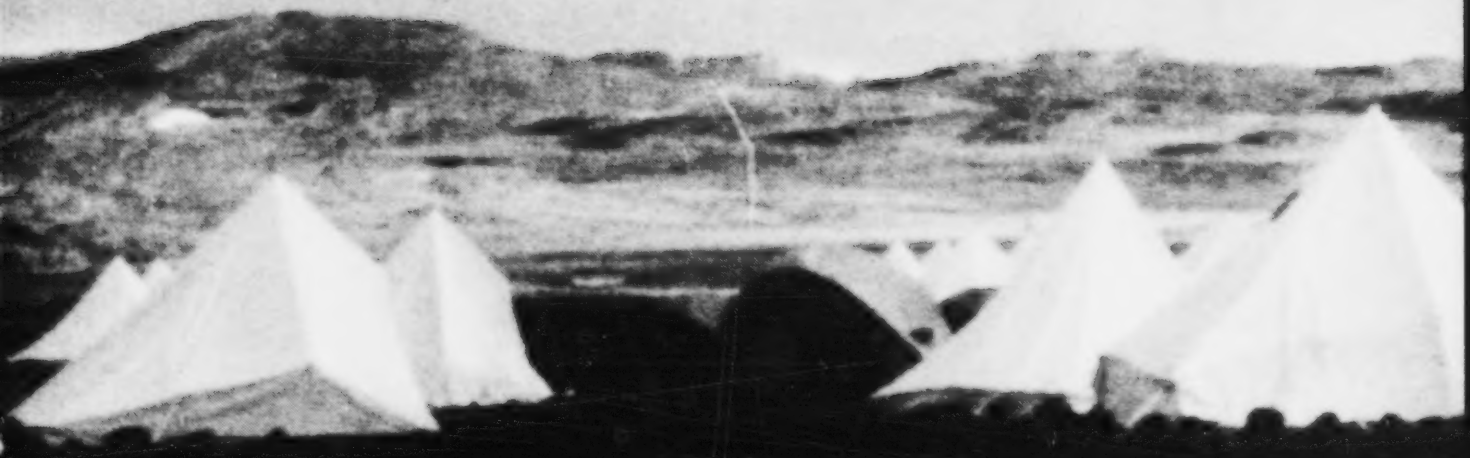

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The 2000 southern Ontario seismic project[1]

K. Ouassaa, D. Forsyth, and D. White

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Abstract: In the summer of 2000, approximately 400 km of crustal seismic reflection data were acquired across parts of southern Ontario from the Ottawa River valley to Lake Erie. Nine profiles traversed parts of the exposed and covered Central Metasedimentary Belt of the Grenville Province to provide constraints on Grenville crustal structure and the interaction of the Paleozoic sedimentary section with the underlying Precambrian basement. The survey was conducted under LITHOPROBE to augment and extend the LITHOPROBE Abitibi–Grenville transect, with funding provided by Ontario Power Generation and Talisman Resources. Scientific supervision of the survey was provided by the Geological Survey of Canada and the University of Western Ontario. The seismic work complements the higher resolution southern Ontario aeromagnetic survey data acquired in 1999.

Résumé : Pendant l'été 2000, on a recueilli des données de sismique réflexion profonde sur environ 400 km dans certaines parties du sud de l'Ontario, entre la vallée de la rivière des Outaouais et le lac Érié. On a établi neuf profils s'étendant dans des parties exposées et enfouies de la Ceinture métasédimentaire centrale de la Province du Grenville, afin de définir les contraintes qui s'exercent sur l'écorce terrestre dans cette province géologique et sur l'interaction entre la section sédimentaire paléozoïque et le socle précambrien sous-jacent. Les travaux ont été entrepris dans le cadre du projet LITHOPROBE et avaient pour but de prolonger le transect Abitibi-Grenville du projet LITHOPROBE. Ils ont été financés par les sociétés Ontario Power Generation et Talisman Resources. La Commission géologique du Canada et la University of Western Ontario en ont assumé la supervision scientifique. Ces levés de sismique réflexion profonde complètent les données aéromagnétiques à plus haute résolution recueillies dans le sud de l'Ontario en 1999.

[1] Contribution to LITHOPROBE

INTRODUCTION

The objective of the LITHOPROBE Abitibi–Grenville transect is to image and quantify the third dimension of the Grenville Orogen. Previous LITHOPROBE seismic studies (Milkereit et al., 1992; White et al., 1994) provided a regional tectonic and structural framework for southern Ontario, identifying further questions that guided the new data acquisition. The data were collected by Kinetex Inc. of Calgary, Alberta (D. Harrison, unpub. rept., 2000).

The survey includes approximately 400 km of deep-sounding seismic reflection data acquired along nine profiles between the Ottawa River valley and the Niagara Peninsula (Fig. 1). Data from the new seismic profiles will address three main scientific objectives of Grenville structural studies from the near-surface to depths exceeding 60 km.

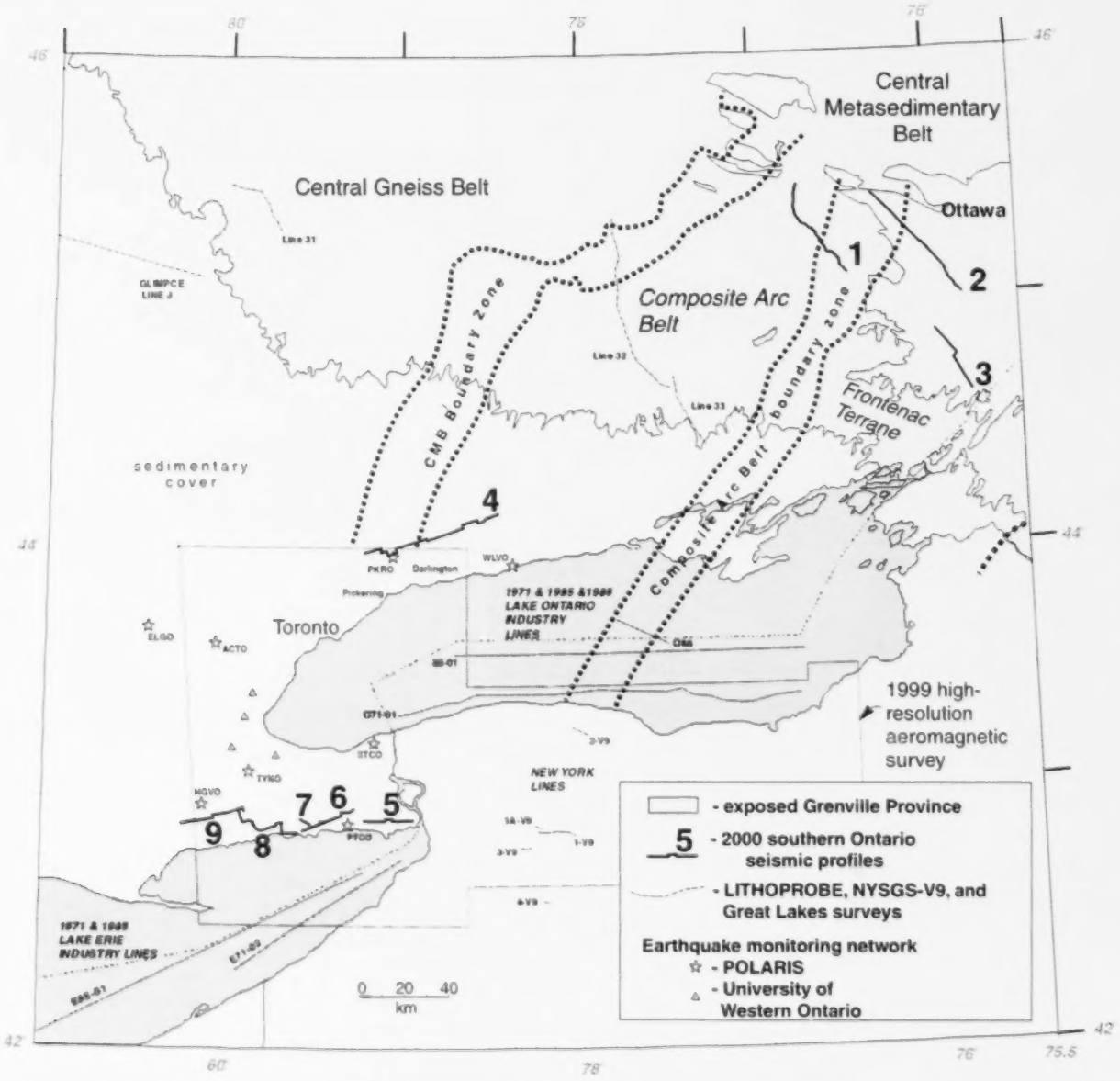
Central Metasedimentary Belt
Central Gneiss Belt
Ottawa
Composite Arc Belt
CMB Boundary Zone
Composite Arc Belt boundary zone
Frontenac Terrane
sedimentary cover
Toronto
1971 & 1985 &1988 LAKE ONTARIO INDUSTRY LINES
1999 high-resolution aeromagnetic survey
NEW YORK LINES
1971 & 1988 LAKE ERIE INDUSTRY LINES
1 2 3 4 5 6 7 8 9
- exposed Grenville Province
5 - 2000 southern Ontario seismic profiles
- LITHOPROBE, NYSGS-V9, and Great Lakes surveys
Earthquake monitoring network
- POLARIS
- University of Western Ontario
0 20 40 km

Figure 1. Regional tectonic setting and locations of seismic profiles (southern Ontario seismic survey, LITHOPROBE, NYSGS-V9, and Great Lakes surveys).

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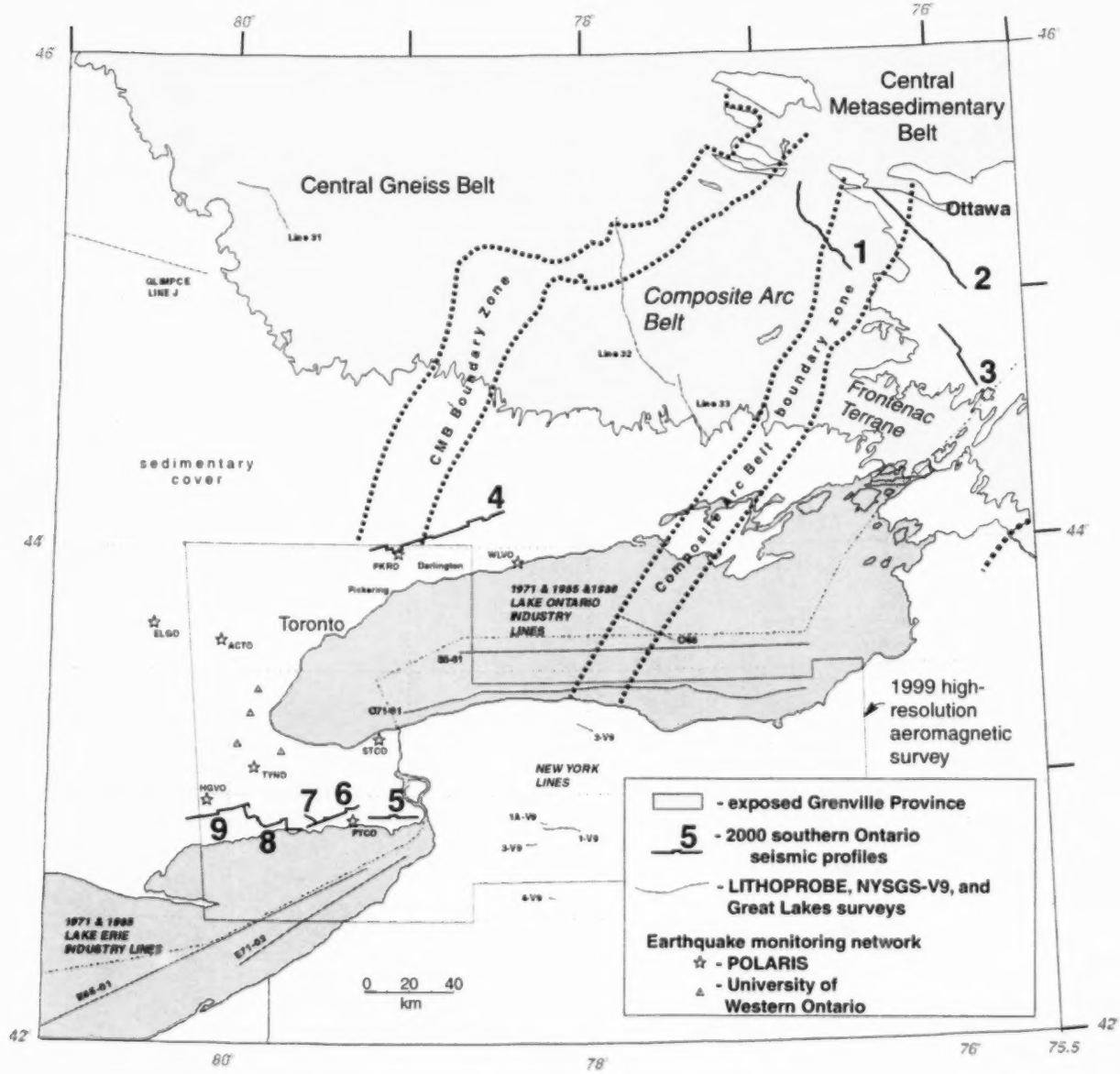

Figure 1. *Regional tectonic setting and locations of seismic profiles (southern Ontario seismic survey, LITHOPROBE, NYSGS-V9, and Great Lakes surveys).*

SCIENTIFIC OBJECTIVES

Structure of the Grenville Orogen in Ontario

A postulated Himalayan analogue, the Grenville Province, provides one the best examples of an exhumed continental collision zone and records a history of the Laurentian continental margin before the collision nearly 1 billion years ago.

The new data will provide constraints on the three-dimensional regional architecture of the Grenville Province in southern Ontario and characterize geological domains and boundaries not covered in previous surveys. As shown in Figure 1, profiles 1 to 3 cross from the Composite Arc Belt to the Ontario part of Frontenac Terrane. These fundamental subdomains and the Composite Arc Belt boundary zone represent key missing pieces in our knowledge of the subsurface geological framework of the Central Metasedimentary Belt. Profile 4 crosses the projected subsedimentary location of the Central Metasedimentary Belt boundary zone, a first-order collisional boundary between parauthochthonous rocks of the Laurentian margin and allochthonous terranes of the Central Metasedimentary Belt (Rivers et al., 1989). This boundary zone was not completely crossed in the original LITHOPROBE surveys. The new data will test the hypothesized southward extension of the Central Metasedimentary Belt boundary tectonic zone and define along-strike variations in the nature of the boundary. Finally, profiles 5 to 9 provide a second crossing of the postulated sub-Phanerozoic extension of the Central Metasedimentary Belt boundary zone and additional coverage of the previously poorly imaged Central Gneiss Belt (parauthochthonous rocks of the Laurentian margin).

SEDIMENTARY–PRECAMBRIAN BASEMENT INTERACTION

The basement cover in southwestern Ontario consists of northerly thinning Paleozoic strata of the Appalachian Orogen and unconsolidated glacial till. The basal cover section may also include pre-Paleozoic material with local accumulations several hundred metres thick. The economically important sedimentary cover hosts oil and gas deposits, potable groundwater, and industrial construction stone. Fluid pathways within the sedimentary rocks and porous basement rocks form conduits for potential groundwater contamination. Our knowledge of the interaction of these sedimentary rocks with the underlying Precambrian basement has seriously lagged behind the accelerated pace of development in southern Ontario. Profiles 4 to 9 image a significant section of the Quaternary cover and Appalachian Orogen to provide new information on Precambrian basement–cover interaction. Profile 4 will provide a 75 km long section of the Oak Ridges Moraine and underlying structure. Glacial till deposits such as the Oak Ridges Moraine are important components of acquifer systems, but the role of the underlying basement in contributing to regional subsurface fluid flow is not well documented. In the area of the Oak Ridges Moraine, detailed shallow seismic models from the Oak Ridges NATMAP Project can be integrated with the new seismic images of the cover and underlying basement to improve our understanding of this major aquifer.

The exploration model for oil and gas includes basement trends and reactivated structures as primary influences on the formation and retention of hydrocarbon deposits. Profiles 5 to 9 will provide a regional benchmark for petroleum-related studies in southwestern Ontario. Faults that can be identified within the Precambrian basement rocks and followed into the overlying sedimentary cover may constrain the ages and amount of possible post-sedimentary fault activity.

EARTHQUAKES IN AN INTRACONTINENTAL SETTING

Although moderate and small earthquakes have been recorded (e.g. magnitude 5.5 in upstate New York in April 2002; magnitude 5.2 near Toronto in November 1996; magnitude 1 to 3 events occur about 10 times a year), large earthquakes are unknown in the historical record of southern Ontario. Seismic risk is amplified as a result of increased population density and critical infrastructure in the area. A high-resolution aeromagnetic survey was flown in 1999 (Fig. 1) to improve the database that is the subject of an ongoing debate concerning the structural and seismogenic significance of gravity and magnetic anomalies in the Lake Ontario area (Wallach et al., 1998). The new seismic data will aid the search for displacements of well defined stratigraphic markers that may imply reactivation of Precambrian basement structures.

Ultimately, with the increased earthquake monitoring capabilities of the POLARIS network (Fig. 1), an attempt can be made to verify a possible link between imaged subsurface structures and earthquake activity.

RECORDING PARAMETERS

Municipal permission was obtained for the survey routes (Fig. 1) that followed a network of secondary roads. These roads were selected to optimize coverage of the target structures, minimize disruption of adjacent infrastructure (buildings, pipelines, etc.), and simplify survey geometry. Recording station spacing was decreased from 25 m to 12.5 m for profiles 5, 6, and 7 in an attempt to obtain a higher resolution seismic image of the shallow structure in an area of both special tectonic and hydrocarbon interest near eastern Lake Erie. The recording parameters are outlined in Table 1.

DATA PROCESSING

Data processing was done during 2001 at GSC Ottawa by K. Ouassaa on a Sparc Ultra (Enterprise 450) workstation using Promax (v7.0) and Insight (V5.1) software from ITA/LandMark. The processing sequence described in Table 2 was accomplished with special attention to the statics

Table 1. Southern Ontario seismic survey data-acquisition parameters.

Field crew	Kinetex Inc.
Date	May-June 2000
Client	Geological Survey of Canada
Instrument type	I/O System 2000
Trace/Record	963
Record length	46 s
Sample rate	4 ms
Filter	¾ Nyquist
Fold (% CDP)	6000%
Nominal vibroseis source parameters	
Source array	4 vibrators in-line
Pattern length	120 m
VP interval	100 m
Sweep length	28 s
Sweep type	Linear
Sweep frequency	5Hz - ¾ Nyquist
Nominal receiver array parameters	
Group interval	12.5 m
Geophone/Group	9 geophones, with 1.56 m spacing

correction and velocity analysis. The results presented are migrated seismic sections using Kirchhof time (Fig. 2, 3, 4) and depth migration (Fig. 5).

PRELIMINARY SECTION FROM THE NIAGARA PENINSULA

Paleozoic rocks underlying the Niagara Peninsula and adjacent lakes Erie and Ontario form part of the northerly thinning edge of the Appalachian Orogen. The mainly Paleozoic cover sequence thickens southward from nearly 900 to 1000 m beneath the Niagara Peninsula to about 1500 m beneath eastern Lake Erie (Forsyth et al., 1994). Beneath the Niagara Peninsula, well cuttings indicate a variation in the thickness of basal Cambro-Ordovician material from tens to hundreds of metres suggesting deposition on an eroded Precambrian surface with considerable local relief.

Table 2. Processing sequences.

Brute stack and parameter tests: - Demultiplex: IEEE SEG D 86360 bpi produced by Kintex Inc. to Promax format - Crooked line geometry application, first-break picking and trace editing - Elevation static correction: final datum elevation 200 m, 2000 m/s replacement velocity - Select deconvolution, filtering, and scaling - Velocity analysis: semblance and constant velocity stack - Stack - Migration parameter tests: phase shift time migration, Kirchhoff time, and depth migration
Signal enhancement: - Minimum phase spiking deconvolution (operator length: 80 msec, white noise: 1%, window: (Offset: 0 m: 100–800 ms, Offset: 1200 m: 300–800 ms) - Ormsby band pass filter 15-20-70-80 Hz, with NOTCH filter frequency at 60 Hz - 2D weighted median filter (1,1,1; 1,2,1; 1,1,1), with linear move-out velocity of 1800 m/s) - Time-invariant spectral balancing (15-20-70-80 Hz , 4 panels) - 2D weighted median filter (1,1,1; 1,2,1; 1,1,1), with linear move-out velocity of 1800 m/s) - Automatic gain control (AGC), with 250 operator length
Final stack: - Signal enhancement data input - Normal move-out correction, with stretched mute tolerance of 30% - Weighted stack - Automatic gain control (AGC), with 250 operator length
Time-migrated seismic section: - Kirchhoff time migration with the same RMS velocity used for the stack - Automatic gain control (AGC) with 250 operator length
Depth-migrated seismic section: - Convert RMS velocity to smoothed velocity interval - Kirchhoff depth migration (75 Hz maximum frequency) - Automatic gain control (AGC) with 250 operator length
Crust seismic plot: - Stacked or migrated seismic section - Coherency filter (semblance smooth (59, 59)) - Traces mixing 5 traces (1,1,1,1,1) - plot_thresh

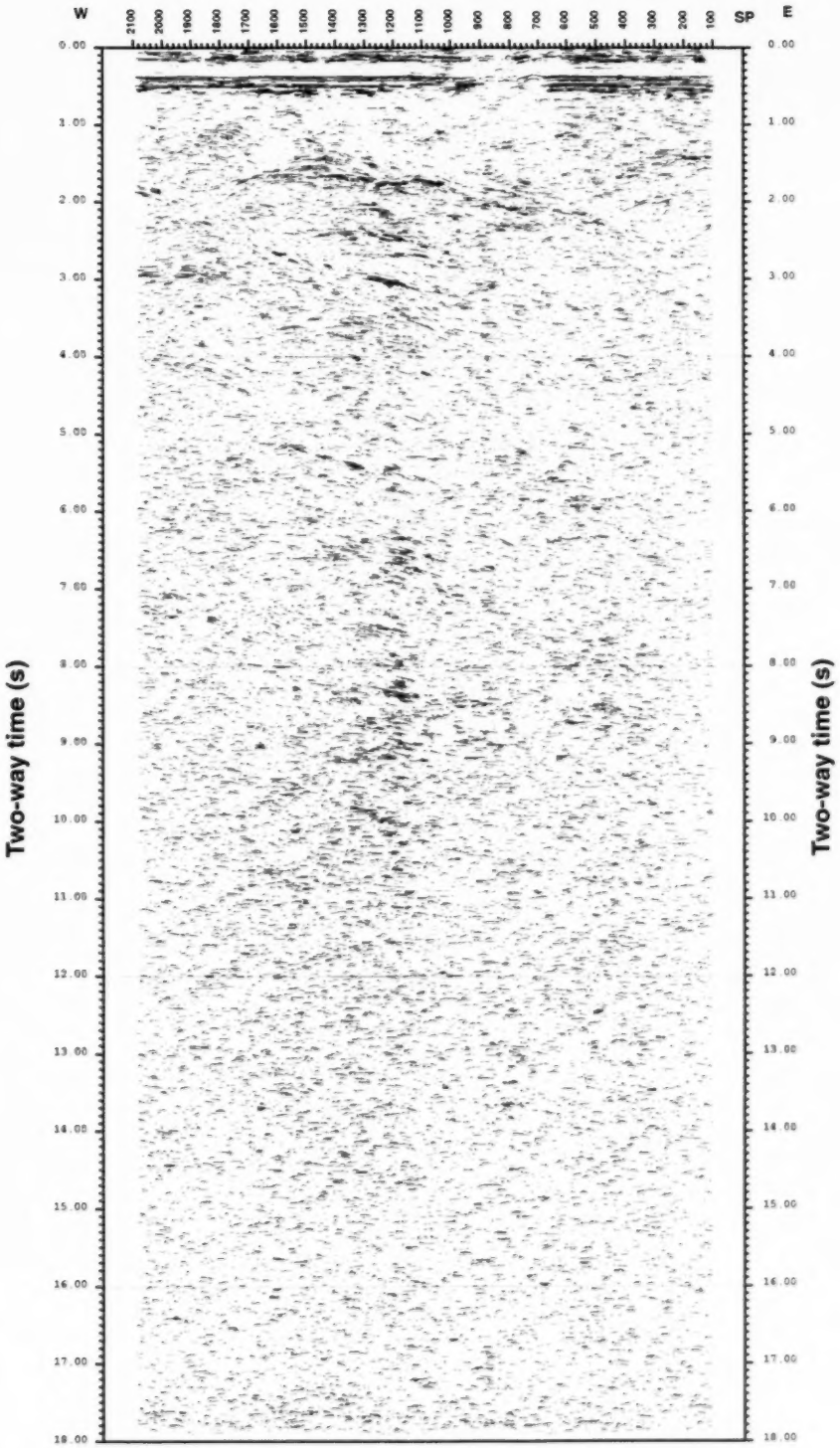

Figure 2. *Time-migrated seismic section (distance, two-way time) for southern Ontario seismic survey line 5.*

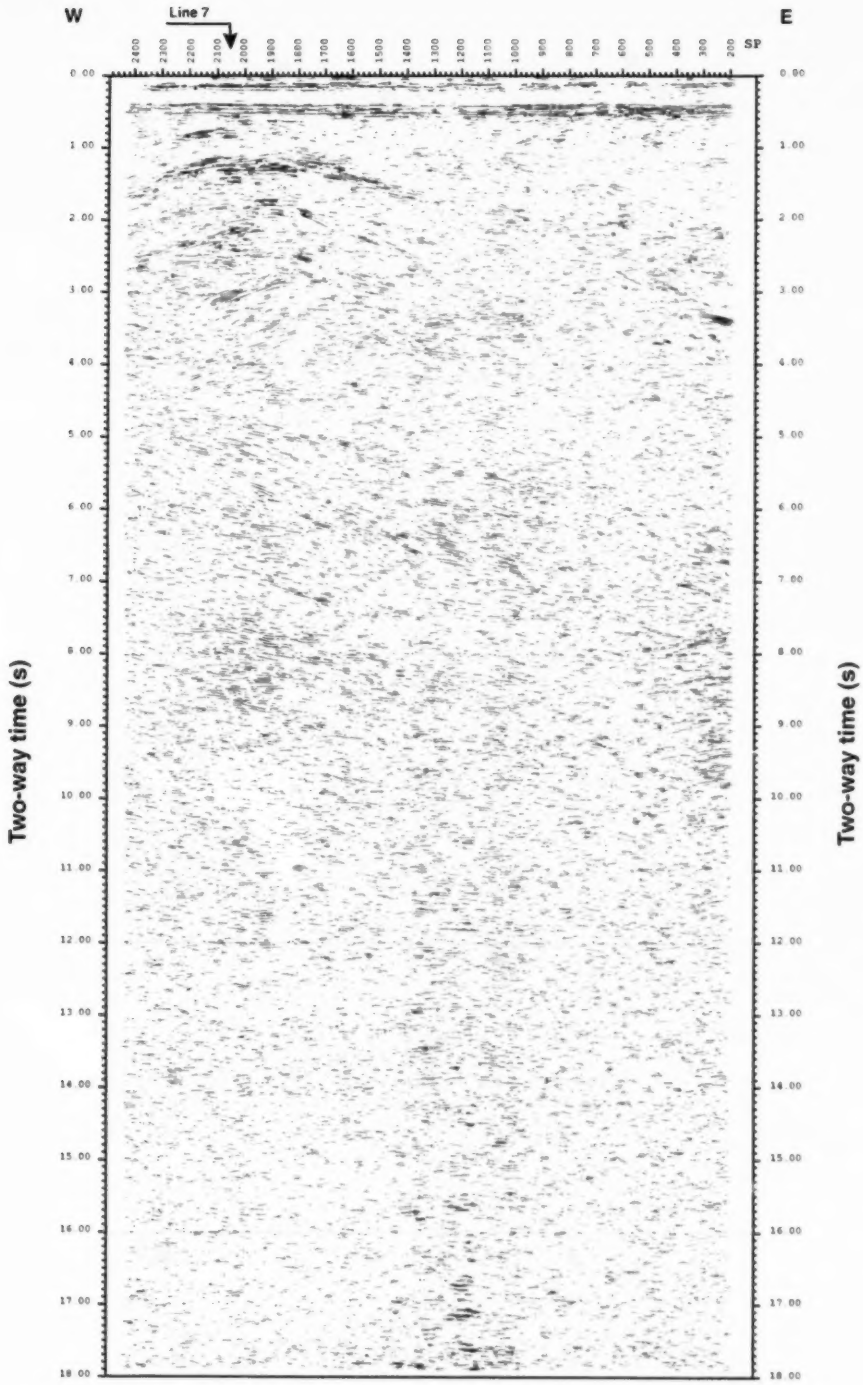

Figure 3. *Time-migrated seismic section (distance, two-way time) for southern Ontario seismic survey line 6.*

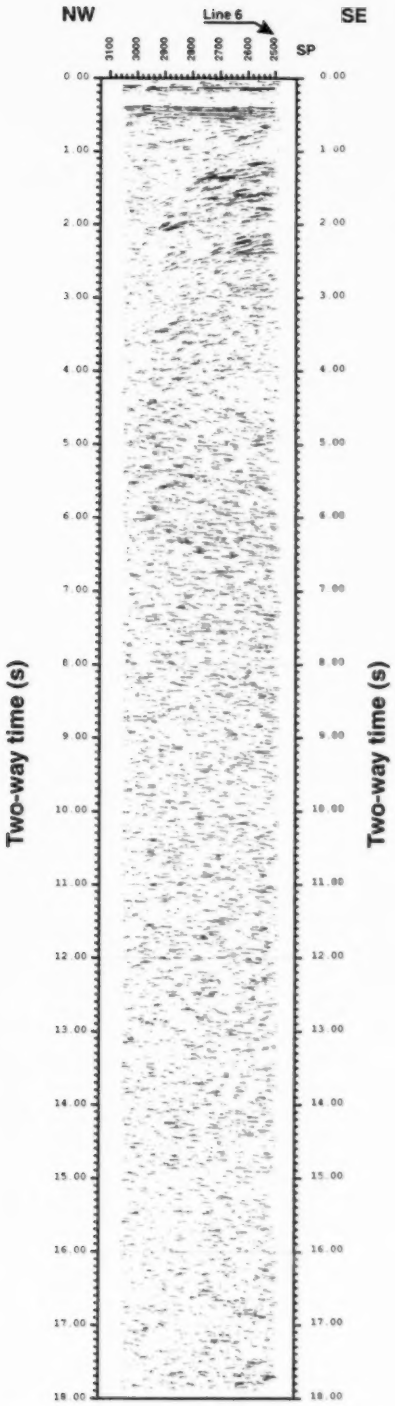

Figure 4. *Time-migrated seismic section (distance, two-way time) for southern Ontario seismic survey line 7.*

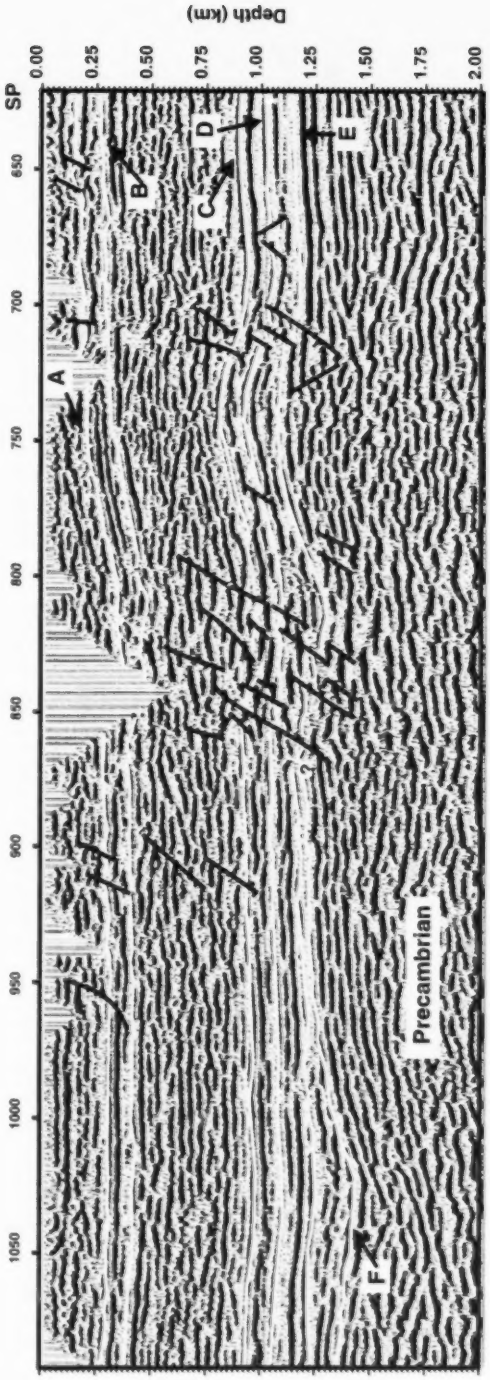

Figure 5. *Enlarged portion of depth-migrated seismic section (distance, depth) for the Paleozoic–Precambrian part of line 5. Reflectors A, B, C, D, E, and F are shown.*

suggested that periodic fracturing coincided with plate tectonic events related to Appalachian mountain-building processes some 450 to 350 million years ago.

Linear magnetic anomalies and drill cuttings have been interpreted as evidence of ductile deformation domains extending from the exposed Central Metasedimentary Belt and Central Gneiss Belt to beneath the eastern Lake Erie area (Easton and Carter, 1995). Magnetic anomalies associated with the northeast-trending Central Metasedimentary Belt boundary zone suggest that a related structure may extend beneath the area of western Lake Ontario, the Niagara Peninsula, and eastern Lake Erie.

As indicated in Table 1, profiles 5, 6, and 7 beginning just west of the Welland Canal were recorded with a reduced station spacing of 12.5 m in an attempt to improve the resolution of the Paleozoic section and provide constraints for the hydrocarbon exploration model for the eastern Lake Erie area. Figures 2, 3, and 4 show preliminary versions of profiles 5, 6, and 7 from the eastern Niagara Peninsula. The generally horizontal reflectors of the Appalachian strata are succeeded at a depth of about 0.5 s by shallow-dipping events associated with the Precambrian basement.

The Paleozoic strata maintain a generally constant thickness of approximately 1180 m along line 5 and thicken slightly to approximately 1250 m at the end of line 6. A well located about 200 m north of shot point 1205 from line 5 indicates a Paleozoic section thickness of 992 m. The Paleozoic strata dip slightly southward on line 7. The Paleozoic section thickness is 1150 m at the end of line 7 and 1200 m at the intersection with line 6.

Paleozoic strata are characterized by strong and continuous reflectors. We distinguish five characterisitc reflectors (A to E, Fig. 5) on the basis of correlation with formation depths in a nearby well north of line 5. The reflector–formation character is very similar to that observed on seismic line 1 of the NYSGS-V9 experiment in western New York State (Ouassaa and Forsyth, in press).

Reflector A is discontinuous along lines 6 and 7, occurs at a two-way time of 0.14 s (300 m), and is correlated with the Devonian–Silurian transition. Reflector B is discontinuous along lines 6 and 7, occurs at a two-way time of 0.18 s (425 m), and is correlated with the Silurian–Ordovician transition. The bottom of the Queenston shale may be represented by a segmented reflector along the eastern part of line 5 (stations 510 to 650) at a two-way time 0.33 s (800 m). This reflector is unclear on the other lines. Reflector C is strong and continuous, occurs at a two-way time of 0.40 s (950 m), and is correlated with the top of the Trenton Group. Reflector D is strong and continuous, occurs at a two-way time of 0.45 s (1075 m), and is correlated with the Trenton–Black River transition. Reflector E is strong and continuous, occurs at a two-way time of 0.48 s (1200 m), and is correlated with the Trenton–Cambrian transition.

The formations mentioned above show little variation in thickness along the lines. For example, Black River strata are approximately 50 m thicker on lines 6 and 7 than on line 5. The generally horizontal stratification is interrupted locally where Trenton and Black River strata show small vertical undulations of about 50 m over a distance of 2.5 km, and larger undulations of 125 m over a distance of approximately 1 km (Fig. 5). Possible fractures or faults with an apparent maximum offset of approximately 50 m and apparent dips of 50° to 80° both to the east and to the west appear to be associated with the undulations in the Trenton and Black River strata. The transition from Potsdam–Theresa (Cambrian) to Precambrian is located at a two-way time of approximately 0.52 s (1275 m). The thickness of the Cambrian strata may vary locally from 25 m to 250 m.

Beneath the Paleozoic strata, the seismic sections (Fig. 2, 3, 4) show strong linear and arcuate Precambrian basement reflector geometries, similar to those observed on LITHOPROBE lines to the north (White et al., 1994, 2000) and beneath Lake Ontario (Forsyth et al., 1994). A change from easterly to westerly or northwesterly dips is seen immediately below the Paleozoic strata near the centre of line 6 (Fig. 3). Three zones of reflectivity can be distinguished (Fig. 2, 3, 4). The first, extending from just below the Paleozoic to about 4.5 s, is characterized by strong linear and arcuate reflections, with both easterly and westerly apparent dips of 15° to 25°. The second zone, from about 4.5 s to 9.2 s, is dominated by linear reflections with apparent easterly dips varying from 15° to 30°. A third zone, from approximately 9.2 s to 18s, features mainly short linear horizontal reflections. The Moho transition beneath this part of the Niagara Peninsula is not characterized by strong reflections.

SUMMARY

This report presents an outline of the 2000 southern Ontario seismic survey and a preliminary look at the first crustal seismic images from the Niagara Peninsula. The seismic sections document Paleozoic thicknesses, structural features, and Precambrian basement elements that form new contributions to the structural framework beneath southern Ontario. The apparent deformational feature observed east of the intersection of lines 6 and 7 is a rare seismic example of a structural change in the relatively undisturbed Paleozoic strata of southern Ontario. Additional aspects of this feature, its relationship to the underlying Precambrian basement, and its association with the west side of the Niagara Escarpment are all topics for future study.

The interesting change from easterly to west or northwesterly dips near the centre of line 6 may indicate a change from the predominantly easterly dipping fabric of the Central Metasedimentary Belt to a domain associated more with the Central Gneiss Belt exposed to the north.

The three lines described herein represent three of the five lines immediately north of Lake Erie. Work continues on the processing and interpretation of these and the four other lines of the southern Ontario seismic survey shown on Figure 1. The interpretation of all the survey data will be integrated

with previous LITHOPROBE seismic results and available geological and geophysical information to form a new structural framework for the crust underlying southern Ontario.

ACKNOWLEDGMENTS

The field program succeeded only thanks to the very positive collaboration of the following individuals and organizations: Harold Asmis and Clive Alexander (Ontario Power Generation), Ron Clowes, Andrew Nikiforuk (Lithoprobe Secretariat), Timo Von Rudloff, Lynne Davies (Talisman Energy), Dave Eaton, Dave Markus, Charley Murphy, Melissa Burdan (University of Western Ontario), Jean-Claude Paradis, Gervais Perron, Brian Roberts (Natural Resources Canada), Dale Harrison, Darryl Armstrong and field crew (Kinetex Inc.), Matai Surveys, Ontario Ministry of Transport, Enbridge Consumers Gas, Union Gas, and countless gracious landowners along the route.

Profiles 1, 2, 3

Township of Admaston / Bromley
Townships of Bagot, Blythfield, and Brougham
County of Renfrew
Canadian Pacific Railway
Municipal Office of Lanark Highlands
County of Lanark
City of Ottawa
Kitley Township Roads Department
United Counties of Leeds and Grenville
Township of Elizabethtown

Profile 4

Township of Scugog
Uxbridge Township
Whitby Engineering Services
Pickering Municipal Property and Engineering
Town of Oshawa
Region of Durham Works Department
Regional Municipality of York
Town of Whitchurch Stouffville
County of Peterborough
Municipality of Clarington
Township of Cavan, Millbrook, North Monaghan
Township of Otonabee-South Monaghan
Township of Manvers

Profiles 5, 6, 7, 8, 9

Six Nations Public Works
Six Nations Natural Gas
Region of Haldimand Norfolk
City of Nanticoke
Town of Haldimand
Delhi Public Works
CGC Inc., Hagersville
Township of Wainfleet
Port Colborne Public Works
Regional Municipality of Niagara
Fort Erie Public Works
Town of Dunnville

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